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Rapid resumption of interrupted search is independent of age-related improvements in visual search

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ABSTRACT

In this study, 7–19-year-olds performed an interrupted visual search task in two experiments. Our question was whether the tendency to respond within 500 ms after a second glimpse of a display (the *rapid resumption* effect [*Psychological Science*, 16 (2005) 684–688]) would increase with age in the same way as overall search efficiency. The results indicated no correlation of rapid resumption with search speed either across age groups (7, 9, 11, and 19 years) or at the level of individual participants. Moreover, relocating the target randomly between looks reduced the rate of rapid resumption in a very similar way at each age. These results imply that implicit perceptual prediction during search is invariant across this age range and is distinct from other critical processes such as feature integration and control over spatial attention.

Introduction

An important aspect of everyday behavior is the ability to select one object from among many and to act on it. This ability improves in child development, as all who work with young children know firsthand. For example, there is no better place to hide a pair of shoes from a kindergarten child than to place the shoes on the child's bed. A child who ordinarily expects to find his or her shoes beside or under the bed can search for a long time before finding the shoes in plain view. As this example illustrates, search success is governed by more than the magnitude of the physical contrast that distinguishes an object from its background. Expectations based on past experience are also critical.

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In this study, we explored how the implicit expectations of recent experience play a role in age-related changes in visual search.

The study of visual search has contributed much to our understanding of human attention (Wolfe, 1994, 1998) and how it differs from one end of life to the other (Plude, Enns, & Brodeur, 1994). For instance, we know that there are separable cognitive components of a successful visual search. One of these is *feature integration,* the binding of visual attributes that distinguish the target item from nontarget items. According to feature integration theory (Treisman & Gelade, 1980), to find a red square among green squares and red circles, the color red must be specifically associated with the square shape. The theory states that human vision is limited by the constraint that two or more attributes (e.g., color and shape) can be integrated (or bound) only for one item at a time. This leads to the consequence that the search time for conjunction-defined targets increases directly with the total number of items present in a scene. The slope of the search time function over the number of items, therefore, is taken to be an index of the efficiency of feature integration.

A second aspect of successful search is the ability to move the spotlight of attention from one item to the next until the target is found. According to attentional orienting theory (Posner & Peterson, 1990; Posner & Raichle, 1994), each item must be assessed with respect to its potential match to the search image, and the spatial focus of attention must be disengaged from the current item, moved to a new item, and then reengaged on that item. When age-related improvements in feature integration and spotlight movements were isolated in a study of visual search over the lifespan from 6 to 72 years of age, Trick and Enns (1998) concluded that the increased efficiency of both feature integration and spotlight movement were behind the age-related improvements in search during the school years but that only a decreased efficiency of spotlight movement was responsible for the age-related decline in search ability at the later end of life.

More recently, the importance of implicit prediction in visual search has been identified through studying searches that are momentarily interrupted and then resumed (Lleras, Rensink, & Enns, 2005). In an interrupted search task, participants search a display with brief *looks* of 100 to 500 ms that are momentarily interrupted by *waits* of 1000–3500 ms (we use *epoch* to refer to each cycle of one look followed by a wait). Adult participants are generally quite successful in these tasks, being able to identify the target on 75% of the trials within three epochs and with accuracy levels of 95% or more. But following the second and subsequent looks, two distinct phases in the response time (RT) distributions can be seen. One is an early phase of correct responding that begins at around 200 ms and peaks between 300 and 399 ms, and the second is a later phase of responding that peaks in the range of 600–799 ms. Illustrations of these two phases can be seen in the RT distributions from Experiment 1 in the current study (see Fig. 2). In contrast to the pattern of responses that occur following a single first look (<2% of responses between 0 and 499 ms), subsequent looks commonly result in 30–50% of responses occurring within 499 ms (i.e., in Epochs 2, 3, and beyond). This is the operational definition of *rapid resumption* that we use in the current study.

Lleras et al. (2005) interpreted rapid resumption within a *reentrant theory* (Di Lollo, Enns, & Rensink, 2000; Enns & Lleras, 2008), according to which all perception involves an iterative process of information, with a higher level associated with object representations and a lower level associated with precategorical sensory input. Perceptual awareness is achieved once a prediction about a candidate object is created and confirmed against the current sensory input. For example, a precondition for awareness is that the reentrant activity in the system matches the sensory input. If there is no match, then perceptual awareness of the object generating the prediction does not occur and the system generates a new prediction regarding the current sensory information, which is believed to be the basis of visual backward masking (Enns & Di Lollo, 2000). On this account, rapid resumption of an interrupted search reflects the benefit of forming implicit predictions of a target item based on an incomplete glimpse of a scene on a previous look (Enns & Lleras, 2008).

Evidence supporting the hypothesis that rapid resumption is an index of perceptual prediction comes from several findings. First, both rapid resumption and report accuracy are sharply reduced if the original display is not re-presented following a single look (Lleras et al., 2005). This suggests that participants do not have explicit awareness of the prediction. But it also indicates that rapid correct responses depend on the predicted information being confirmed in the sensory array; merely forming the prediction is not enough. Second, rapid resumption fails to occur when the first display consists